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ABSTRACT

This paper deals with the different aspects of solving technical problems. To solve a technical problem in an optimal way it is not enough to consider the appropriate technical and technological principles, the different organizational, economical, and ergonomical principles must also be taken into account. The didactic aspects of solving technical problems at different levels are described. The different levels include: the functionality level. conceptualization, design and construction, and the production and maintenance level. Rules that must be considered when didactically designing a technical problem or its simulation are also described. It is concluded that different problem-solving based exercises stimulate student's creativity especially in technical and technological fields. Contains 12 references. (JRH)

THE TECHNICAL PROBLEM AND ITS DIDACTIC FUNCTION

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1. Introduction

The question how to come from a given starting situation to a desired end situation is usually the essence of each technical problem. The first step in a problem solving process is therefore an abstract definition of differences between the starting and the end situation. With other words we must define the tasks which we have to perform to reach the desired situation. In the technical field we usually indicate these tasks as "functions". A technical system that fulfills the requested tasks or "functions" represents the problem solution.

To fulfil the requested tasks or "functions" we need an appropriate technical system. If we cannot perform the desired tasks with some known technical system, we have to deal with the technical problem. From the didactic point of view we have a similar situation also in the case where an appropriate technical system already exists but we do not know it. With other words, if we have to deal with a problem situation or not, does not depend only on the situation itself but also on the subject who must solve the problem.

For most technical problems we usually know the starting and the desired end situation, but we do not know the needed transformation activities between these two situations. To find out these activities and to carry on an optimal process often represents a problem situation.

The technical problem is always multidimensional. To solve a technical problem in an optimal way it is not enough to consider the appropriate technical and technological principles, but we must consider also different organisational, economical, ergonomical and other principles important for a concrete problem. With other words, we must respect the environment demands and restrictions if we want to solve a technical problem in an optimal way.

2. Different levels of technical problem

The process of solving a technical problem can proceed at different levels: at the functionality, conceptualisation, design and construction, production and maintenance level. It depends on problem description whether we need to solve it at all or only at one or few of described levels.

2.1. Functionality level

To solve a certain technical problem at the **functionality level** (for example, how to make a profile from raw material) we first define the global function or task (for example, raw transformation). In the next step we try to find out which subfunctions must be done to perform the global task (for example, raw warming, raw rolling, profiling). Each of these subfunctions is a self contained function so that we can define its subfunctions again.

We can illustrate this level with a simple task "how to make a profile from raw material". Adequate problem situation is schematically shown in figure 1. In the first step of problem solving we can analyse the main function and decompose it into appropriate subfunctions or part functions (figure 2).

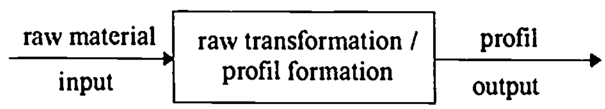


Figure 1: Example of main function

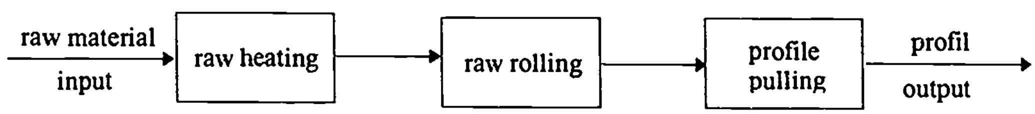


Figure 2: Main function decomposed on subfunktions

To perform the described tasks we need material, energy and information. We can show how to apply all kinds of resources in a transformation process with an adequate "function net" or "function structure" (figure 3).

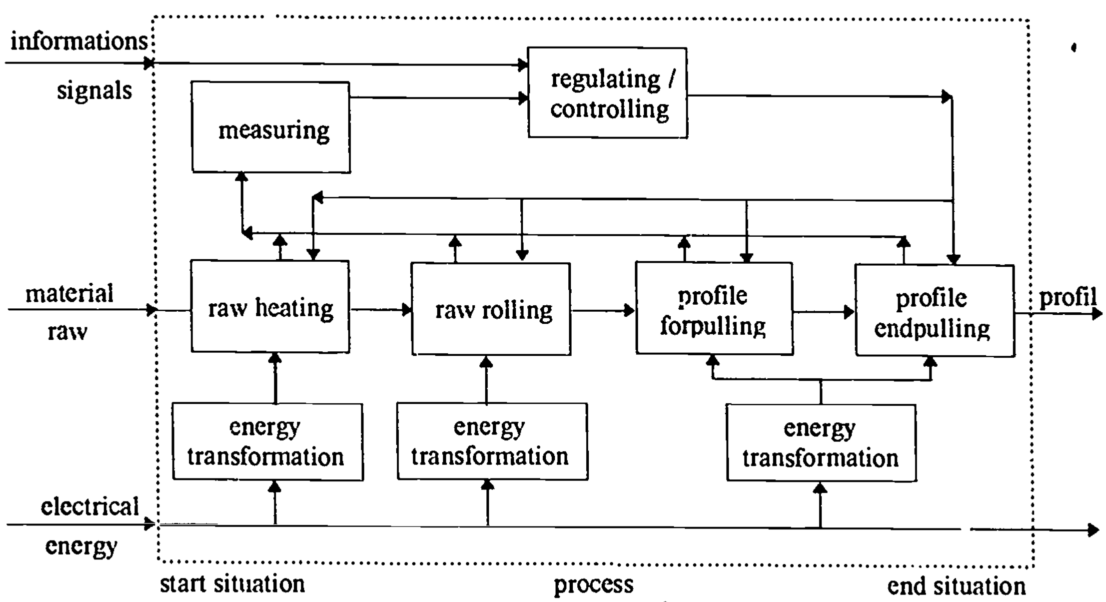


Figure 3: Function net

In the same manner as in the described technological example we can analyse functions of different machines, devices and other technical systems.

2.2. Conceptualisation level

After function and subfunction analysis for a chosen technical system we can define the necessary elements we need to perform the demanded tasks or functional principles on which the elements are based (solution principles). In simple cases we have the elements for different functions already available. An example of such a case is shown in figure 4.

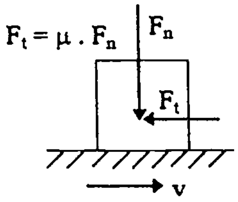
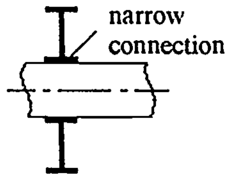
subfunction	physicle principle	solution principle	elements
→ rotation moment transmission →			- wedge - bung - cork - rabbet axis

Figure 4: Subfunction and solution elements

When solving a technical problem at the **conceptualization level** we first try to define all possible solutions for each subfunction. With adequate combining of these partial solutions we can later develop a few different concepts of more or less acceptable conceptual solutions (figure 5). In the case of "raw transformation", for example, we can choose among four solutions for the function "raw warming": the electric, gas, oil or coke stove. If we presume that we can also find four different possibilities of "raw rolling" and three possibilities of "profiling" we can have at the end 48 different technical concepts (4.4.3 = 48). At the end we can choose the most acceptable solutions if we have defined the adequate appraisal criteria in advance.

subfunction	principles and solution elements			
1. raw heating	electrical stove	gas stove	oil stove	coke stove
2. raw rolling	one way rolling dual frame	two way rolling turn dual frame	two way rolling trio frame	continuous rolling line
3. profiling	pulling bank	rolling cylinder	pressing machine	
conceptual variants	1	2	3	... up to 48

Figure 5: Principles and solution elements for function "raw forming"

2.3. Design and construction level

At the conceptualisation level we define different elements which fulfil the main function and subfunctions of a technical system.

A technical problem at the **design and construction level** is how to connect many different partial solutions into a functional entirety or technical system. We usually define the dimensions of different system elements and the material of which are they made. There are also many limitations that we have to consider at this problem solving level. The final solution must be documented.

As a simple case of problem solving at the design level we can take a task to design "a hydraulic regulating system for rectilinear motion". We presume that we have already defined all subfunctions and adequate elements at the preceding conceptualisation level. We must now install - at the design level - all single elements like pumps, valves, pipes, tubes and other hydraulic elements in the complete hydraulic system, which will perform the defined task. The final solution is schematically shown in figure 6.

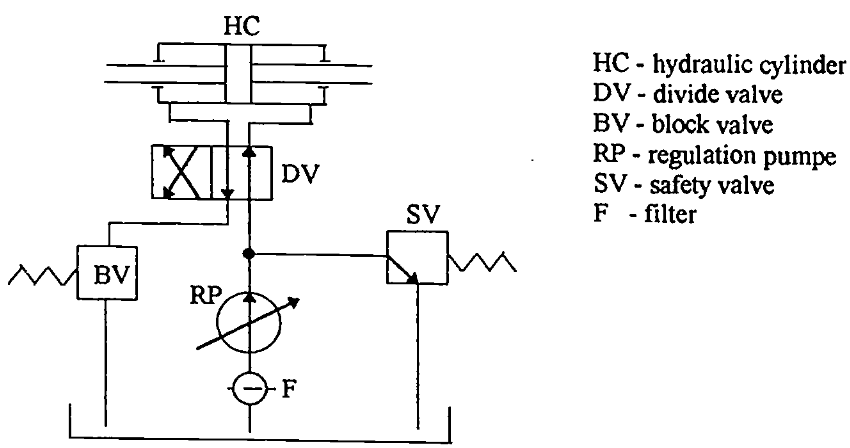


Figure 6: Open hydraulic system with regulation pump

In some cases it could happen that we have no standard element for a certain function. In such cases we must therefore define the geometrical form and dimensions of the element and the material of which it will be made. At this level we must also make different calculations and take into account certain restrictions. Those are the tasks at the construction level of technical problem solving.

2.4. Production level

At the **production level** we need appropriate technical documentation. The technical problem at this level is how to produce different system elements and how to connect them into complete technical system. On the basis of technical plans and drawings we plan different technological procedures, tools and production machines for production and installation.

We will try to show the essence of problem solving at the production level by using the task "define a technological process for producing a handle". We made the needed constructions and drawings at the preceding design and construction level. The appropriate technological process is schematically shown in figure 7.

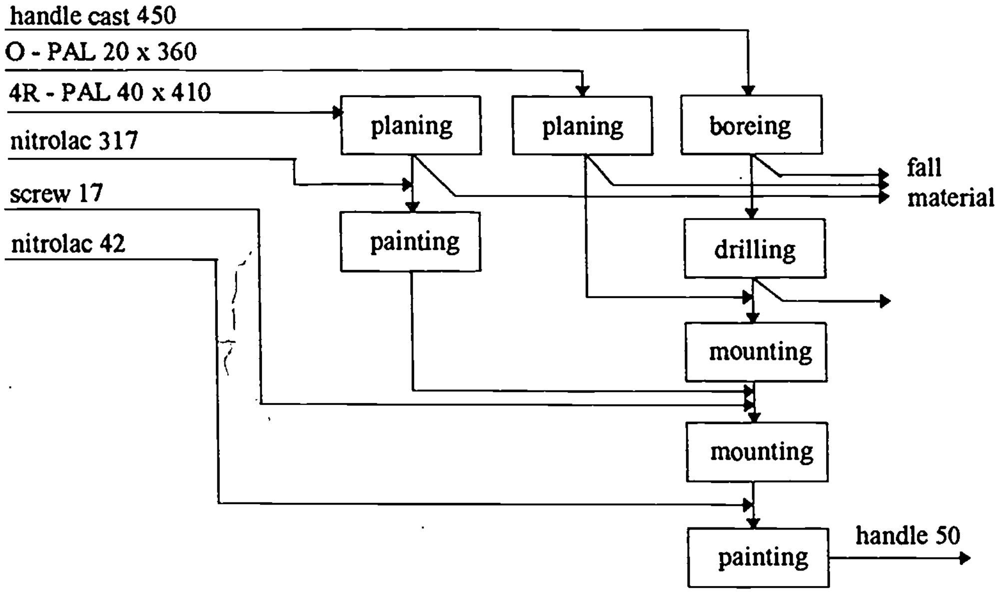


Figure 7: Scheme of technological process

Together with technological activities the needed controlling, transporting, storing and other tasks can also be defined at this level. We can define the needed tools, measuring instruments and performing machines. A lot of empirical data like the data about performing speed, cut angles and other technological data are used at the production level of technical problem solving.

2.5. Maintenance level

A good example of a problem solving method at the maintenance level is the use of the so called defect or "mistake analysing tree", which we built so that we deny system main function and its subfunctions.

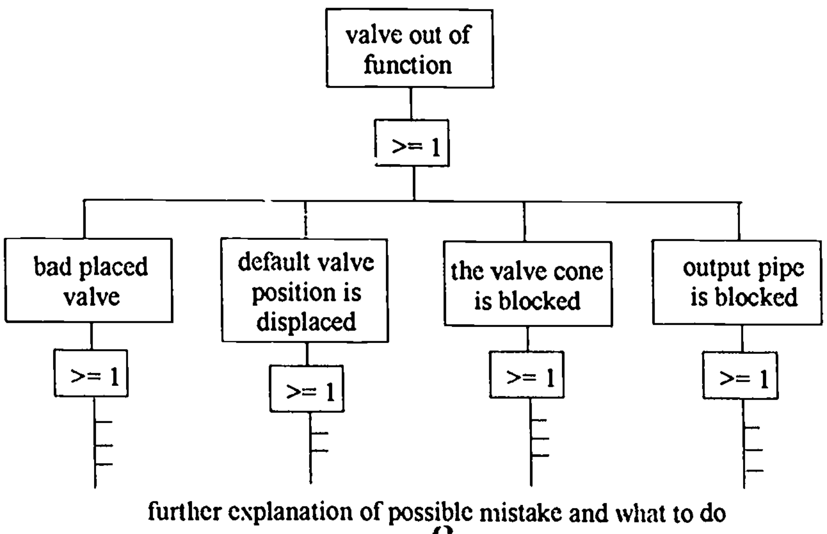


Figure 8: Mistake analysing tree

Out from denied subfunctions we carry out adequate activities, which we perform in the case of system breakdown. An example of how to use this method in the task "find a reason for defect of safety valve" is schematically shown in figure 8.

3. Didactic design of technical problems

One of the significant aims that we have in the context of technical education for a changing future is education for creative work. The main condition for creative work is the ability of creative thinking. A good way to develop creative thinking is problem solving.

The didactic design of technical problems could be done in two different ways. The essence of the first mode of problem based exercise is that we describe and define the chosen technical function for the fulfilment of which we try to find an appropriate technical system or technical solution during the learning process (figure 9). Because the final solution is unknown to the problem researcher, we can classify this type of didactically designed exercises as a group of "re-discovery" or "self-discovery" methods.

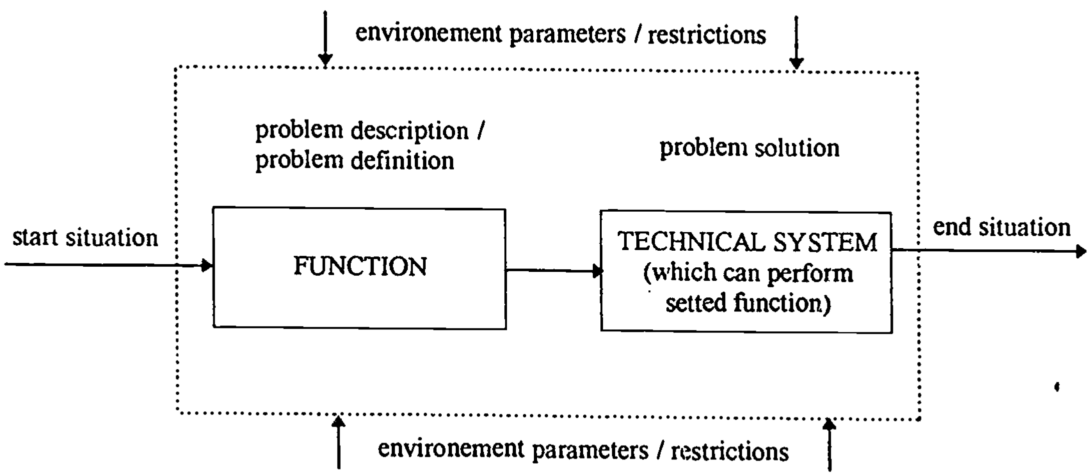


Figure 9: Functional approach to technical problem

The second mode of problem based exercise is the opposite of the first mode. We describe a technical system the function of which is unknown or only partially known. In this case a problem must be didactically designed in a way that stimulates the process of finding and discovering and does not allow only a simple function interpretation.

Both types of described problem solving exercises must stimulate productive, convergent and divergent modes of thinking. The best way is that we use both types of exercises mutually.

Some rules must be considered by didactically designing of technical problem or in its simulation. The first rule is that a didactically designed technical problem must have all the basic characteristics of a real technical problem. The second rule is that the problem must be described in a manner which will motivate the learner to think and to act in a problem solving oriented way. This is possible only in a situation in which the learners recognize the way to the solution. The problem itself must be interesting enough and it should be solved only through combination of different knowledge and experiences. The problem itself must be so structured that it stimulates team work.

We have been experimenting with technical problem solving at our school for a longer period. As a result of our study we have defined eight basic types of didactic problem solving exercises. A short description of the eight basical types is presented in the continuation.

(1) "Re-discovery" or "self-discovery" of the chosen technical system at all mentioned levels of technical problems

We can design this type of exercises at all levels of a technical problem. We usually put the students in the role of experts with the task to develop a new technical system. This type of cases is very open therefore a solving process demands a very high level of creative thinking.

(2) "Finding" certain missing functions of the chosen technical system and "finding" new solutions and improvements; "adapting" a certain technical system or its elements to new conditions and requirements

In practice a very frequent task is to improve the existing technical system or to adapt it whole or some of its elements to new requirements. The daily dealing with such problem situations is typical for constructors, fitters and maintenance workers. It is not accidentally that they are usually the ones who give the majority of innovation suggestions in each company.

This type of problem solving exercises demands a lot of divergent thinking, out of established methods and proceedings. For this kind of problem solving it is typical that we already know the system function and its subfunctions. The main task is therefore to find out original solutions and alternatives for a certain already existing system.

(3) "Re-discovery" or "self-discovery" of certain system elements with which one can cover some gaps in functionality of the chosen technical system; from the didactic point of view those types of exercises are relatively reduced and closed

Finding solution elements for missing subfunctions in a functionality structure of a certain technical system systematically, is typical for this kind of problem solving exercises. From the didactic point of view the problem situation in such kind of exercises is very reduced or simplified (relatively closed system). The advantage of this reduction is that we easily adapt the contents of exercises to the knowledge and experience level of students. The second positive side is that we can use this kind of exercises also for simple problem situations, which could be solved within one or two school hours.

(4) Use and transfer of adapted problem solving principles in a new situation; past experiences are used for developing "new technical elements or systems"

The functionality principles of different technical systems and their elements could be recognized through appropriate function analysis. If we join two or more single solutions in the general principle, we could use it for solving all problems of the same type. The transfer of past experiences and known general principle for solving similar probiems in new situations is the essence of this kind of exercises.

This type of exercises is usually designed in a way which demands of students that they independently discover different technical systems by combining and gathering different already known elements. To perform this task they must first define the main function and its subfunctions and then they look for solution elements with which they can build the appropriate technical system. The problem situations are often very open for this kind of exercises, so there are enough opportunities to develop several original solutions.

From the didactic point of view, if the problem situation is too open, we must close it in some way. We can, for example, give the students a solution principle for a similar problem situation and then demand of them that they use this principle in a new but similar situation.

(5) Converting a real technical system into a simplification model; experimenting with simulation models or with "virtual technical systems"

We use different models in the technical field. At the construction level we often use different physical models (shames, plans, models etc.) for describing existing or hypothetical technical systems. The advantage of such models is that they are very easy to understand.

Another kind of models are so-called symbolical models. These are logical and mathematical models used for different calculations. This kind of models are abstract and therefore difficult to understand.

The third kind of models are simulation models. With their help we try to explain dynamically technical systems and processes. For describing dynamically properties of certain technical system we use the mathematical and logical methods. For experimenting such kind of models are usually computer supported. We can describe this kind of models also as virtual technical systems.

For problem solving exercises which are based on symbolical and/or simulation models we need appropriate cognitive structure, composed of epistemic (data about reality) and heuristic knowledge (analyzing, comparing and other methods). This type of exercises stimulate students to use their knowledge in new problem situations.

(6) "Discovery" causes of breakdowns in defected technical systems

The easiest way to discover causes of breakdown or interruption in a certain technical system is to analyze its function and subfunctions. In practice we systematically test different system elements, step by step. In this way we decompose the system in its elements in order to try out which of them is defective.

We can practice the same analyzing process also only mentally. We define the hypothesis, collect data to prove it and at the end we evaluate the final results. The most important thing is to recognize the relation between system elements and its main function, between elements and the whole system.

For the didactic design of this kind of exercises it is important that we have enough starting data and information. We must describe a problem situation so far that we can find a solution by testing different hypotheses. The second possibility is that we present the students with a certain technical system, the functional structure of which is completely unknown ("black-box method"). In this case we know only the main system function so that we must find out the functional structure and single subfunctions by experimenting with the system. Only if we know adequate functions and subfunctions can we evaluate single elements whether they function correctly or not.

(7) Establishment of natural science rules by which a chosen technical system is functioning

For this type of problem solving exercises it is typical that students themselves discover on which natural science rules the main function and/or subfunctions of some known technical system are based. This is a good way for understanding better relations between different system elements and to support the understanding of basic rules.

The most widely used method in this case is problem oriented experimentation. We distinguish between two types of problem oriented experiments: experimenting in real (laboratory experimenting) and in virtual technical systems (experimenting in mind). In the latter case experimentation is based on an abstract mind or mental model that is necessarily a simplified picture of complex reality. Only under such conditions we can imagine a structure and processes with a complexity beyond our abilities of perception. In mental experimenting field we operate with very simplified technical systems but such type of exercises nevertheless demands a very high level of abstract thinking.

(8) Exercises with the characteristics of technical improvisation

In practice we often meet different tasks for the performance of which we use some kind of technical improvisation. Typical for technical improvisation is that in urgent cases we use different non original elements to support further functionality of a certain technical system (for example, we can use a screw-driver as a chisel or a compass point as a point of a drawing needle).

We have two basic problem situations in this case. In the first case we must change the main function of the system with non original elements, and in the second, we must assure unchangeable main function of the system with the use of non original elements. In both cases we have to deal with the restructuring of certain elements and their function. Such activity at the level of technical improvisation stimulates the same mental processes as other problem situations.

Conclusion

In the introduction part of our paper we try to define the technical problem and its structure. We found out that different levels of a technical problem could be of interest for our further didactic examination. Those levels were: functionality level, conceptualization level, design and construction level, production and maintenance level.

In the second part of our study we focus on the didactic aspects of solving technical problems at different levels we described. We discuss briefly some rules that must be considered when didactically designing a technical problem or its simulation.

With our paper we want to introduce such study methods which stimulate creativity. The opinion that most classical study methods do not stimulate student's creativity enough led us to make some didactic experiments with a problem solving method.

The main conclusion of our experimental work is that different problem solving based exercises stimulate student's creativeness especially in technical and technological fields. The student answers in questionnaires told us the same. They prefer problem solving methods to other study methods.

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